Cultural Heritage and Internet of Things

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ABSTRACT

Ancient structures and historical buildings represent invaluable assets for future generations. They need to be preserved as much as possible since, as cultural heritage, provide with irreplaceable cultural, social and historical wealth, not only for the local heir communities, but in many cases for the whole human kind. In the context of today's technologies, the Internet of Things (IoT) paradigm represents one of the most effective ways for monitoring "things" around us. Cultural Heritage stays as one important application field for IoT, since conservation of cultural heritage sites can be significantly improved by means of an efficient and well-designed monitoring and control system.

However, there are many approaches to apply IoT on Cultural Heritage use cases. For this reason, in this paper we discuss IoT architectures currently used for monitoring and preservation of historical buildings, and identify existing challenges IoT applications are still facing to become a fundamental part in the conservation of the everlasting cultural values these buildings represent.

CCS CONCEPTS

• **Applied computing → Architecture (buildings)**.

KEYWORDS

IoT, Cultural Heritage, preservation, historical buildings.

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1 INTRODUCTION

Cultural heritage represent past and current values and traditions in every society and plays a mayor role in the creating a belief system and a sense of identity. United Nations Educational, Scientific and Cultural Organization (UNESCO) classifies cultural heritage as tangible and intangible cultural heritage[29]. Additionally, tangible cultural heritage is classified as:

- Movable cultural heritage (e.g., paintings, sculptures, numismatics, manuscripts)
- Immovable cultural heritage (e.g., monuments, archaeological sites, religious/historical buildings)
- Underwater cultural heritage (e.g., shipwrecks, underwater ruins and cities).

Preserved Cultural heritage sites can contribute to the economic growth of local communities thanks to tourism. However it requires policies to be put in place for their preservation. According to UNESCO, as more tourists visit cultural heritage sites worldwide, some sites are being neglected in terms of preservation policies. The monitoring of these cultural heritage sites plays a fundamental role to preserve the current state of cultural heritage sites to ensure a proper conservation for future generations.

In order to perform this monitoring, IoT technologies are inherently the most logical alternative. The Internet of Things (IoT) paradigm makes an object interact with the surrounding environment, making him "intelligent". Combined with sensing technologies, wireless sensor networks allows for remote monitoring and management of objects in an efficient manner [22, 30, 36]. This can be used e.g., to track environmental conditions in spaces, detect structural changes in materials, or alert of an anomalous presence in forbidden areas. Such IoT applications can improve preservation, appraisal and fruition of culture heritage.

There are a large number of IoT technologies to be applied in the cultural heritage preservation use cases. From Low Power Wide Area Network (LPWAN) technologies (e.g., LoRA, SigFox, NB-IoT, DASH7, LTE-M, etc.) using a long-range cellular infrastructure, Wireless Local Area Networks (WLAN) technologies for mid-range communication (e.g., IEEE 802.11ah) or Wireless Personal Area

Network (WPAN) technologies (e.g., Zigbee, BLE, Z-Wave, WirelessHART, ISA100.11a, 6TiSCH, etc.) based on a more infrastructureless approach. As a result, each particular cultural heritage preservation use case can benefit from different IoT architectures and technologies.

This work aims to carry out a critical analysis of IoT technologies applied to cultural heritage found in the literature, with emphasis in preventive conservation use cases. Finally, we discuss the challenges existing in IoT technologies when used for conservation of historical buildings located in remote areas, and open research questions will be raised.

2 STATE OF THE ART OF CULTURAL HERITAGE AND IOT

When applying IoT to Cultural Heritage preservation, there are many approaches found in the literature. This work focuses on two of the most important:

- Cultural Heritage IoT systems applied to enhance cultural spaces. These systems are often focused on indoors places (although not always), and normally aim to preserve protected areas or to improve visitors' user experience.
- IoT systems for the conservation of Cultural Heritage. These system aim to monitor and control the heritage' environmental and material conditions to optimally preserve them.

2.1 IoT for the Enhancement of the Cultural Heritage

Cultural, historic and archaeological spaces such as museums or castles can integrate the concept of IoT improve the overall visiting experience in a wide range of domains. Visitors to heritage sites each have different motivations, expectations, and needs. Museums often attempt to deal with this by offering different experiences that visitors can partake of. This can include e.g., specific guided tours or education activities for school groups. This is the approach followed by [5, 14], were they present IoT prototypes whose aim is to transfer "smartness" to cultural sites by applying different communication and sensor technologies. These works propose new applications to enhance the interaction of visitors in the museums or improve the navigation in the cultural spaces.

In order to support these use cases, different IoT architectures can be defined. The work in [15] presents an IoT system to represent and manage the object interaction inside cultural spaces with the visitors.

It points towards an IoT application design space where a set of configurable sensor nodes are able to transform cultural spaces, in an indispensable dynamic instrument for valorization, knowledge diffusion of cultural assets.

Accordingly, the authors in [24] also analyze how technology can play a crucial role in supporting museum visitors and enhance their overall museum visit experiences. The content delivery systems can provide relevant information and, at the same time, allow visitors to get the level of detail and the perspectives up to the level they are interested. In the same line, the authors in [34] propose a mobile recommender system for the Web of Data. Web of Data is term used to refer to the Semantic web, where RFD/XML models are exploited to publish structured, linked data between entities within different data sources [10, 39]. They propose to leverage such semantic approach to supply information needs of tourists in context-aware on-site access to cultural heritage.

In the same way, DALICA is presented in [16] as an outdoor alternative to the previous works. DALICA is an agent-based ambient intelligence system for outdoor cultural heritage scenarios (i.e., Villa Adriana, Italy) that uses information about nearby points of interest, based on user location provided by GPS and Galileo location systems. Similarly in [6], the authors propose a general architecture of a SNOPS (Social Network of Object and PersonS) platform and presents a specific smart deployment related to the archaeological site of Herculaneum, Italy.

However, besides improving user experience, IoT systems can also be directly applied to enforce preservation and increase the security of cultural heritage sites. One clear example of this use case is introduced in [21], where an IoT-based integrated security system is capable to provide the site with visitor security and cultural heritage protection. In this work, one of the unnoticeable advantages of using IoT for security in cultural heritage sites, such as flexible security, is unveiled. Flexible and adaptable security can enable, for example, to adjust a secure perimeter to allow visitors with disabilities (e.g., partially blinded visitors) to temporally exceed it to better observe an artwork.

The previous works aim to mainly use IoT to enhance the cultural heritage site, in terms of user experience or security. In order to improve the user experience, these systems use IoT and multimedia technologies to enhance visitors enjoyment, offering them a different way of discovering a museum or a historical site. On the other hand, they can offer an improved control of protected areas by deploying sensors and actuators over the site. However these systems do not really help to the conservation of cultural heritage "per se", requiring additional preventive conservation IoT systems to unveil the IoT full potential on Cultural Heritage.

2.2 IoT in Cultural Heritage for Preventive Conservation

The other side of the coin of using IoT for cultural heritage are the preventive conservation use cases. The IoT's idea of "monitoring things" perfectly matches with monitoring any object in a cultural heritage site to prevent any future damage and to optimize their environmental conservation conditions.

2.2.1 Preventive Conservation. . In order to take the necessary actions before it is too late, a preventive conservation is fundamental to pro-actively control the deterioration of cultural heritage. Long-term monitoring and predictive maintenance of the assets' physical conditions can significantly mitigate the damage and reduce future restoration costs [1, 27, 28].

Depending on the intrinsic nature of each cultural heritage asset, deterioration causes are subjected to the influence of different physical parameters. For example, artworks suffer from stress caused by physical agents such as temperature, humidity, radiation, or chemical agents (e.g., CO2, SO2, O3, mineral salts, etc.) [17]. Meanwhile, temperature and humidity play a major role on archaeological structures because they are mostly built on stone [25].

Generally, abrupt changes of temperature and relative humidity (RH) may cause serious damage in all the different kind of objects, such as non-isotropic material deformation or detachment in multi-layered materials [37]. In hygroscopic materials, such as wood panels, which are the mainstay of many artworks, mechanical changes and deformations could also occur [20]. In the case of frescoes, soluble salts and moisture are the very common causes of deterioration. Therefore, early detections of dangerous levels of these physical parameters are essential to avoid this type of damage [19]. However, in order to ensure a safe, fully preventive conservation, environmental variables should not only be long-term monitored, but also predicted and foreseen with enough time to react (e.g., frosts or heatwaves). For this reason, IoT preservation systems should also perform data analytics in order to learn patterns and detect dangerous oscillations [4, 7].

2.2.2 IoT and Preventive Conservation. From a point of view of preservation of Cultural Heritage, the authors in [3, 9, 11, 23, 33] present clear examples of using preservation technologies to solve existing problems. These approaches are normally based on a WSN architecture that can be roughly divided in three parts: the sensor-based communication network, integrated multi-modal gateway and a centralized monitoring and data analytics platform deployed in the cloud.

Such approaches are usually characterized by 1) low power consumption of sensor nodes, 2) self-forming, self-healing wireless sensor networks, 3) pseudo-infinite storing capacity in the cloud and 5) low cost network deployment and operation. All these combined features make these approaches robust, cost-effective and easily-to-deploy solutions specially interesting for preventive conservation. The most common technologies used to build WSNs and to transport the sensor data are open or standard technologies such as WiFi, LoRaWAN, Sigfox or IEEE 802.15.4. However, some authors choose commercial solutions such as the Hobo data-loggers [2, 38].

Other advantage of deploying WSNs to perform preventive conservation is that WSN are normally noninvasive, and do not require the installation efforts of a wired network. This make these approaches more scalable and flexible than a traditional wired sensor networks, such as the ones presented in [19, 20, 31, 32]. However, wired approaches, although present evident limitations, are sometimes the only option to monitor unreachable areas without wireless connectivity (e.g., hidden points behind thick stone walls). Because of this, some works point towards a hybrid architecture [18, 26]

3 THE CHALLENGES FOR IOT IN HERITAGE SITES

The above discussed works present different approaches to use the IoT for cultural heritage. However, there is not a "one-size-fits-all" solution for every heritage site. Each site has its own particularities, needs and constraints. Many heritage sites may be isolated in rural areas with minimal connectivity, lacking of on-site technical support and limited power availability. Other sites may be in urban areas where strict security measures are required, and site assets cannot be under no circumstance altered. While in some cases they have to deal with large crowds intensively using multimedia systems, other cases may require ultra-low latency monitoring, or sensors with a battery lifetime of years. For this reason, we argue there are still many open research paths within IoT-on-Heritage. We have identified the following areas as the most relevant ones:

A. Dealing with limited connectivity. Connectivity is perhaps the biggest challenge for many heritage sites. In terms of in-site connectivity, the new trends are rightly pushing to go wireless because of the many advantages wireless connectivity offers in terms of scalability and flexibility. However some particular sites may require hybrid wireless-wired solutions to achieve 100% in-site coverage. Additionally, special attention should be paid to ensure ultra-high reliability, avoiding data inconstency and favouring redundant systems whenever possible. Regarding external connectivity, sites located in remote areas are the ones with more limitations for data backhauling to the cloud, since sometimes they lack of basic 2G/3G/4G coverage. Low-cost solutions using WiMAX, long-distance WiFi and VSAT have been proposed, however cost-effective solutions still need to be derived for each site [35].

B. Energy-efficiency. Energy-efficiency is an important area for further work in IoT in general, but particularly relevant for deployments for cultural heritage. Although, energy-efficient sensing may be relevant to optimize battery lifetimes in network nodes, it is not the biggest priority. Radio energy consumption can be one (or more) order of magnitude larger than other parts of the WSN nodes [8]. Because of this, achieving an energy efficient communication system with a low duty-cycle is currently the best way to achieve battery of years. However in general, low duty-cycle MAC protocols suffer from low performance in terms of latency, bitrate and reliability. A trade-off study for different heritage use cases may determine which protocols are most suited for each site.

C. Deployment, configuration and maintenance. Although sometimes neglected, logistic issues such as deployment, configuration and operation of IoT systems are often problematic. Many sites have huge economy budgets to employ technicians and network operators to perform these tasks. However many small, less popular cultural heritage sites lack of the means for a complex installation and operation. Currently there are technologies that allow easy deployments and configurations (e.g., WiFi WPS), which may be preferred [13]. However these solutions may not provide with the network security required in a cultural heritage site. For this reason, solutions that aim to both provide strict security and out-of-the-box configurations are worthy to be studied. Operation and maintenance should also be user-friendly and techniques for network self-diagnostics, self-healing and automated maintenance seem to be a promising study field. Finally, special attention needs to be paid to those systems that integrate visitor data and actions across the sites in terms of data privacy management [12].

4 CONCLUSIONS

Internet of Things is still emerging in terms of devices, technologies, applications and domains. While existing IoT research and development has mainly focused on smart homes, smart industries and smart cities, other less studied domains such as smart cultural heritage may offer potential as well. However, applying IoT for enhancing, protection, and conservation of cultural heritage raise a number of challenges, and it calls for new robust, low cost, easily deployable and maintainable systems. This is stated by the diversity of the presented methods and applications in this paper. We have given a limited, but representative overview of the existing IoT solutions applied for Cultural heritage use cases, both for enhancing user experience and for improving preventive conservation. We have highlighted not only the most interesting ones, but also those isolated "exercises" that do not arouse effective interest due to the lack applicability or difficulty for its reuse in different contexts. Finally, we have described existing open challenges in IoT-on-Cultural-Heritage to encourage further research on application domains related with preservation of the tangible cultural heritage.

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REFERENCES

[1] [n.d.]. National Gallery of Australia. Preventive Conservation. Retrieved 20 February 2020 from http://nga.gov.au/Conservation/prevention/index.cfm
[2] [n.d.]. Onset USA. Hobo Data Loggers. Retrieved 20 February 2020 from http://www.onsetcomp.com/
[3] Tommaso Addabbo, Ada Fort, Marco Mugnaini, Enza Panzardi, Alessandro Pozzebon, and Valerio Vignoli. 2019. A city-scale IoT architecture for monumental structures monitoring. *Measurement* 131 (2019), 349–357.
[4] Asaad Al-Omari, Xavier Brunetaud, Kevin Beck, and Muzahim Al-Mukhtar. 2014. Effect of thermal stress, condensation and freezing–thawing action on the degradation of stones on the Castle of Chambord, France. *Environmental earth sciences* 71, 9 (2014), 3977–3989.
[5] Stefano Alletto, Rita Cucchiara, Giuseppe Del Fiore, Luca Mainetti, Vincenzo Mighali, Luigi Patrono, and Giuseppe Serra. 2015. An indoor location-aware system for an IoT-based smart museum. *IEEE Internet of Things Journal* (2015).
[6] Flora Amato, Angelo Chianese, Vincenzo Moscato, Antonio Picariello, and Giancarlo Sperli. 2012. SNOPS: a smart environment for cultural heritage applications. In *Proceedings of the twelfth international workshop on Web information and data management*. 49–56.
[7] Konev Anatoly, Khaydarova Rezeda, Lapaev Maxim, Luanye Feng, Long Hu, Min Chen, and Bondarenko Igor. 2019. CHPC: A complex semantic-based secured approach to heritage preservation and secure IoT-based museum processes. *Computer Communications* 148 (2019), 240–249.
[8] Abdelmalik Bachir, Mischa Dohler, Thomas Watteyne, and Kin K Leung. 2010. MAC essentials for wireless sensor networks. *IEEE Communications Surveys & Tutorials* 12, 2 (2010), 222–248.
[9] Paolo Barsocchi, Pietro Cassara, Fabio Mavilia, and Daniele Pellegrini. 2018. Sensing a city's state of health: Structural monitoring system by Internet-of-Things wireless sensing devices. *IEEE Consumer Electronics Magazine* 7, 2 (2018).
[10] T Berners-Lee. [n.d.]. Linked Data - Design Issues. Retrieved June 1, 2020 from http://www.w3.org/DesignIssues/LinkedData.ht
[11] Xavier Brunetaud, Livio De Luca, Sarah Janvier-Badosa, Kévin Beck, and Muzahim Al-Mukhtar. 2012. Application of digital techniques in monument preservation. *European Journal of Environmental and Civil Engineering* (2012).
[12] Sergio Duque Castilho, Eduardo P Godoy, Tayane WL Castilho, and Fadir Salmen. 2017. Proposed model to implement high-level information security in internet of things. In *2017 Second International Conference on Fog and Mobile Edge Computing (FMEC)*. Ieee, 165–170.
[13] Ioannis Chatzigiannakis, Henning Hasemann, Marcel Karnstedt, Oliver Kleine, Alexander Kröller, Myriam Leggieri, Dennis Pfisterer, Kay Römer, and Cuong Truong. 2012. True self-configuration for the IoT. In *2012 3rd IEEE International Conference on the Internet of Things*. IEEE, 9–15.
[14] Angelo Chianese, Fiammetta Marulli, Vincenzo Moscato, and Francesco Piccialli. 2013. A" smart" multimedia guide for indoor contextual navigation in cultural heritage applications. In *International Conference on Indoor Positioning and Indoor Navigation*. IEEE, 1–6.
[15] Angelo Chianese and Francesco Piccialli. 2014. Designing a smart museum: When cultural heritage joins IoT. In *2014 eighth international conference on next generation mobile apps, services and technologies*. IEEE, 300–306.
[16] Stefania Costantini, Leonardo Mostarda, Arianna Tocchio, and Panagiota Tsintza. 2008. DALICA: Agent-based ambient intelligence for cultural-heritage scenarios. *IEEE Intelligent Systems* 23, 2 (2008), 34–41.
[17] UNI-ENTE NAZIONALE ITALIANO DE UNIFICAZIONI. 1999. UNI 10829-Works of art of historical importance-ambient conditions for the conservation-measurements and analysis. *Milão: UNI* (1999).
[18] Fernando-Juan García Diego, Borja Esteban, and Paloma Merello. 2015. Design of a hybrid (wired/wireless) acquisition data system for monitoring of cultural heritage physical parameters in smart cities. *Sensors* 15, 4 (2015), 7246–7266.
[19] Ángel Fernández-Navajas, Paloma Merello, Pedro Beltrán, and Fernando-Juan García-Diego. 2013. Software for storage and management of microclimatic data for preventive conservation of cultural heritage. *Sensors* 13, 3 (2013), 2700–2718.
[20] Fernando-Juan García-Diego, Ángel Fernández-Navajas, Pedro Beltrán, and Paloma Merello. 2013. Study of the effect of the strategy of heating on the mudejar church of Santa Maria in Ateca (Spain) for preventive conservation of the altarpiece surroundings. *Sensors* 13, 9 (2013), 11407–11423.
[21] Fabio Garzia and Luigivalerio Sant'Andrea. 2016. The Internet of Everything based integrated security system of the World War One Commemorative Museum of Fogliano Redipuglia in Italy. In *2016 IEEE International Carnahan Conference on Security Technology (ICCST)*. IEEE, 1–8.
[22] Jayavardhana Gubbi, Rajkumar Buyya, Slaven Marusic, and Marimuthu Palaniswami. 2013. Internet of Things (IoT): A vision, architectural elements, and future directions. *Future generation computer systems* 29, 7 (2013), 1645–1660.
[23] Dini Hardilla and Agung Cahyo Nugroho. 2018. The Role of Internet of Things to Support Cultural Heritage Inventory in Urban Resiliency Approach: Tradisional House in Bandar Lampung Case. In *2018 International Conference on Information Technology Systems and Innovation (ICITSI)*. IEEE, 193–198.
[24] Tsvi Kuflik, Oliviero Stock, Massimo Zancanaro, Ariel Gorfinkel, Sadek Jbara, Shahar Kats, Julia Sheidin, and Nadav Kashtan. 2011. A visitor's guide in an active museum: Presentations, communications, and reflection. *Journal on Computing and Cultural Heritage (JOCCH)* 3, 3 (2011), 1–25.
[25] MINISTERO PER I BENI E LE and ATTIVITÀ CULTURALI. 2001. *Atto di indirizzo sui criteri tecnico-scientifici e sugli standard di funzionamento e sviluppo dei musei*. Technical Report. Technical report, Italian Law.
[26] Fabio Leccese, Marco Cagnetti, Andrea Calogero, Daniele Trinca, Stefano Di Pasquale, Sabino Giarnetti, and Lorenzo Cozzella. 2014. A new acquisition and imaging system for environmental measurements: An experience on the Italian cultural heritage. *Sensors* 14, 5 (2014), 9290–9312.
[27] Malcolm Lillie, Robert Smith, Jane Reed, and Rob Inglis. 2008. Southwest Scottish Crannogs: using in situ studies to assess preservation in wetland archaeological contexts. *Journal of archaeological science* 35, 7 (2008), 1886–1900.
[28] Shin Maekawa, Frank Lambert, and Jeff Meyer. 1995. Environmental monitoring at Tiwanaku. *MRS Online Proceedings Library Archive* 352 (1995).
[29] Mirjana Maksimović and Marijana Ćosović. 2019. Preservation of Cultural Heritage Sites using IoT. In *2019 18th International Symposium INFOTEH-JAHORINA (INFOTEH)*. IEEE, 1–4.
[30] Mark T Marshall. 2018. Interacting with heritage: On the use and potential of IoT within the cultural heritage sector. In *2018 Fifth International Conference on Internet of Things: Systems, Management and Security*. IEEE, 15–22.
[31] Paloma Merello, Fernando-Juan García-Diego, and Manuel Zarzo. 2014. Diagnosis of abnormal patterns in multivariate microclimate monitoring: A case study of an open-air archaeological site in Pompeii (Italy). *Science of the total environment* 488 (2014), 14–25.
[32] Francisco Javier Mesas-Carrascosa, Daniel Verdú Santano, Jose Emilio Meroño de Larriva, Rafael Ortíz Cordero, Rafael Enrique Hidalgo Fernández, and Alfonso García-Ferrer. 2016. Monitoring heritage buildings with open source hardware sensors: A case study of the mosque-cathedral of Córdoba. *Sensors* 16, 10 (2016).
[33] Angel Perles, Eva Pérez-Marín, Ricardo Mercado, J Damian Segrelles, Ignacio Blanquer, Manuel Zarzo, and Fernando J Garcia-Diego. 2018. An energy-efficient internet of things (IoT) architecture for preventive conservation of cultural heritage. *Future Generation Computer Systems* 81 (2018), 566–581.
[34] Tuukka Ruotsalo, Krister Haav, Antony Stoyanov, Sylvain Roche, Elena Fani, Romina Deliai, Eetu Mäkelä, Tomi Kauppinen, and Eero Hyvönen. 2013. SMART-MUSEUM: A mobile recommender system for the Web of Data. *Journal of Web Semantics* 20 (2013), 50–67.
[35] Javier Simo-Reigadas, Esteban Municio, Eduardo Morgado, Eva M Castro, Andres Martinez, Luis F Solorzano, and Ignacio Prieto-Egido. 2015. Sharing low-cost wireless infrastructures with telecommunications operators to bring 3G services to rural communities. *Computer Networks* 93 (2015), 245–259.
[36] Yunchuan Sun, Houbing Song, Antonio J Jara, and Rongfang Bie. 2016. Internet of things and big data analytics for smart and connected communities. *IEEE access* 4 (2016), 766–773.
[37] Miguel Ángel Valero, Paloma Merello, Ángel Fernández Navajas, and Fernando-Juan García-Diego. 2014. Statistical tools applied in the characterisation and evaluation of a thermo-hygrometric corrective action carried out at the noheda archaeological site (noheda, spain). *Sensors* 14, 1 (2014), 1665–1679.
[38] Giovanni Visco, Susanne Heidi Plattner, Patrizia Fortini, Serena Di Giovanni, and Maria Pia Sammartino. 2012. Microclimate monitoring in the Carcer Tullianum: temporal and spatial correlation and gradients evidenced by multivariate analysis; first campaign. *Chemistry Central Journal* 6, S2 (2012), S11.
[39] Julius Volz, Christian Bizer, Martin Gaedke, and Georgi Kobilarov. 2009. Silk-a link discovery framework for the web of data. *Ldow* 538 (2009), 53.